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A COMPARISON OF MICROWAVE DETECTION INSTRUMENTS

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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A COMPARISON OF MICROWAVE DETECTION INSTRUMENTS

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Division of Electronic Products

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Environmental Health Service
Bureau of Radiological Health
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DIVISION OF ELECTRONIC PRODUCTS

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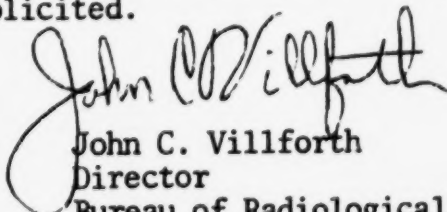
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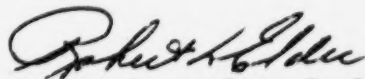
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John C. Villforth
Director

Bureau of Radiological Health

PREFACE

This report presents a comparison of several types of survey instruments designed to detect and measure microwave power density emitted from electronic products such as microwave ovens. The instruments included employ either thermal or electrical means of detection and use a quantitative or qualitative display. The units, which have been tested by the Division of Electronic Products, Bureau of Radiological Health, are evaluated according to the following criteria: accuracy, sensitivity, dynamic range, reliability, ease of measurement, thermal stability, battery life, and cost.



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Division of Electronic Products

CONTENTS

	Page
FOREWORD.	iii
PREFACE	v
ABSTRACT.	ix
INTRODUCTION.	1
TYPES OF MICROWAVE POWER DENSITY INSTRUMENTATION.	1
COMMERCIAL INSTRUMENTS TESTED BY THE DIVISION OF ELECTRONIC PRODUCTS	4
CONCLUSIONS	8
REFERENCES.	9

ABSTRACT

Microwave power density instrumentation can be classified according to intended use, the type of detection system employed, and the type of information displayed. The intended use is subdivided into desirable features for laboratory instruments and survey instruments; method of detection is broken into thermal and electrical detection; and the information display category is divided into quantitative and qualitative display.

Several commercial microwave power density meters which have been tested by the Division of Electronic Products, Bureau of Radiological Health, are compared according to the following criteria: accuracy, sensitivity, dynamic range, reliability, ease of measurement, thermal stability, battery life, and cost.

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A COMPARISON OF MICROWAVE DETECTION INSTRUMENTS

INTRODUCTION

Microwave energy is currently being employed in several different ways, with increased emphasis on use in consumer products. When used as a source of power for a consumer product, microwaves are generally intended to be used in a completely shielded enclosure which allows no access while the microwave source is operating. Since there is concern about the biological effects of such radiation, it is necessary to detect and quantitate leakage from products using this type of energy source.

All of the commercial instrumentation available at the time of this evaluation respond to the electric field intensity and are calibrated in terms of power density measured in free space.

TYPES OF MICROWAVE POWER DENSITY INSTRUMENTATION

Several classification methods for microwave power density instrumentation are possible. The three categories we have chosen are intended use, method of detection, and method of indication. There are two distinct equipment use categories, either as a laboratory instrument or as a survey instrument. A laboratory instrument would ideally be sensitive enough to measure whatever power densities are desired and would be capable of covering an extremely wide dynamic range. It should create no disturbance to the propagating field and should be stable with a very fast response time. It should be able to indicate accurately at any distance from the source.

If the instrument is designed for survey use, it should meet additional major requirements; i.e., it should be lightweight, battery operated with low battery drain, easily readable, rugged, and have a minimum number of switch settings. The probe should be burnout-proof and directionally independent. For operator safety, it is also very important that a survey device not read low when it is in a potentially hazardous field.

The detection methods category can be divided into thermal detectors and electrical detectors. Thermal detectors act on the principle of producing a detectable physical change (temperature) in a thermally sensitive element. This change is then measured, usually by electrical means. There are three general types of thermally sensitive elements in use today. The first is the thermistor. The resistance of the

thermistor decreases when its temperature rises. The thermistor is heated by coupling it to the electromagnetic field. It is the RF (radiofrequency) current which causes the heating of the thermistor, but the detection of this heating is done by measuring the d.c. resistance of the thermistor. Another device closely akin to the thermistor is the baretter which has a positive temperature coefficient of resistance rather than a negative one. These are both known as bolometer detectors, a term meaning any device which changes its resistance as it changes temperature.

Another type of temperature-sensitive device is the thermocouple. A thermocouple produces a voltage when heated. Therefore, all that is necessary to make a detection device from a thermocouple is an antenna and a current or voltage measuring device. Since voltage and current levels encountered when using these detectors are very small, a sensitive meter must be used, generally in conjunction with some type of direct-current amplifier.

A third and rather novel approach to thermal microwave measurement is the air-pressure system. This system involves the measurement of a small pressure change in a confined gas when its container is heated slightly by absorbing some RF energy. The container for the gas is usually some sort of electrical insulator covered by a carbon compound which absorbs RF energy quite well.

The three thermal detection schemes discussed have individual and common deficiencies. They all are, of course, ambient temperature dependent in their simple form. More sophisticated methods of measuring the difference in output from matched thermal detectors with only one exposed to RF heating have been developed, and such instruments are superior for general application.

A somewhat different approach to power density measurement is that of direct electrical energy conversion. The detected RF power directly activates the meter needle for measurement. This effect is accomplished by using a semiconductor diode or rectifier. This device, of the same type as used in early radio sets, rectifies the alternating RF current into direct current which may then be applied to a meter movement calibrated to indicate power. Knowing the effective antenna area, the power density may be calculated. The diode detector type of indicator may be made extremely sensitive. In fact, this is one of the drawbacks of high frequency diodes -- even moderate signal strengths must be attenuated before reaching the detector in order not to overload it. This is sometimes rather complicated and may lead to measurement inaccuracies. This is probably the reason that the thermal detectors are preferred over diode detectors for survey-type power density meters.

With the exception of the air-pressure detector, all detectors or sensors require an antenna to convert the propagating radiofrequency wave into wire-conducted radiofrequency currents which are then detected by either a thermistor, thermocouple, or diode. It is this antenna that determines the major characteristics of the measuring instrument. There are two attributes of an antenna which are important to the user of the instrument: directionality and polarization sensitivity. Directionality of an antenna is the dependence of its response on the direction from which the wave comes. One would like an antenna which is somewhat directional so that the effect of reflections from survey personnel will be minimal, but at the same time it should not be too directional so that orientation towards the source becomes critical.

The second attribute is polarization sensitivity. Polarization of an electromagnetic wave refers to the direction of the electric field vector. This vector may be varying in orientation (random polarization), fixed in orientation (plane polarization), rotating in orientation at the radiofrequency (elliptical polarization), or any combination of these. There is no single antenna which will respond to all polarizations simultaneously. This causes a great problem in antenna design. To achieve true polarization independence, one must use two antennas which are identical to each other except that they accept orthogonal polarizations. The power captured by these antennas must be added arithmetically in the metering circuit, which places added constraints on the design. To design a survey meter with true polarization independence is no easy task. Generally this is accomplished by using two perpendicular dipole antennas with independent detectors.

The third category for classification of microwave power density instrumentation is method of indication. Quantitative methods are an analog scale and digital indication calibrated either in milliwatts per square centimeter or decibels relative to some reference. These methods seem to be the most practical in a laboratory or survey meter. If the instrument is used to measure product performance against a standard then it is very helpful to have the indication in the same terms as set forth in the standard. Visual qualitative devices such as variously colored gaseous glows or an audible alarm which sounds when some power density limit is exceeded are useful devices under certain conditions; e.g., quickly locating microwave leakage from an oven.

COMMERCIAL INSTRUMENTS TESTED BY THE DIVISION OF ELECTRONIC PRODUCTS

The commercial survey instruments which were tested in the DEP laboratory include:

- (1) A pocket dosimeter employing a multiturn coil as an antenna¹
- (2) A preignited neon-mercury tube designed to indicate a microwave field²
- (3) A survey meter employing a dipole antenna with a thermocouple detector³
- (4) A survey meter employing a horn antenna with a thermistor detector⁴
- (5) A survey meter employing a lefthand helix antenna with diode detector⁵

The pocket dosimeter was found to be totally unsuitable as a quantitative instrument. It exhibited marked differences from theoretical values because of RF leakage of the instrument components. The response of the unit was severely dependent on the polarization of the radiation and exposures to extremes of temperature.

The inexpensive instrument utilizing a preignited neon-mercury tube as detector and readout was also found to be unreliable for quantitative measurements for the following reasons:

- (1) Variation of sensitivity between instruments. As stated by the manufacturer of the neon-mercury tube used in the instrument, "The tube was never designed for this application and consequently the gas pressure and other important parameters are not at all controlled for this type of application" (1).
- (2) Variation with time. It has been reported that a tube left unused for some time will often appreciably change its ignition threshold (2). A tube which glows fully at 10 mW/cm² may later fail to detect a considerably stronger field.
- (3) Variation with direction. Different evaluations of the field will be obtained for different orientations of the instrument. Optimally, the instrument glows fully at a level of approximately

¹Model C-1 Dosimeter, Scientific Protection Devices, Inc.

²International Crystal 285 Microlite, International Crystal Mfg. Co.

³Narda Model 8100, Narda Microwave, Inc.

⁴Ramcor Model 1200, Model 1270, Ramcor, Inc.

⁵Wayne-Kerr Rad 200, Wayne Kerr Co. Ltd.

10 mW/cm² in the most favorable orientation -- thus, when the instrument is in any other orientation, the field will be underestimated.

- (4) Subjective nature of determination. There is no definite threshold for ignition or for full tube-length glow. Even with no microwave power present, a faint blue glow is discernible at the ignition end of the tube. As the power level is increased, small blue flashes begin to appear, and their size and frequency are continuous functions of power. There is a wide range between the power density for the first flash which extends the length of the tube, for instance, and that at which the full tube can be said to be glowing.
- (5) Lack of warning of high power density. It was observed that at power density levels between 20 and 100 mW/cm² no change was seen in the quality of the light emitted by the tube.
- (6) Variation with lighting conditions. Especially at low power density levels, the visibility of the blue flashes is considerably enhanced by viewing the tube against a black background or at low ambient light levels.

The principal advantage of this instrument is its low cost (about thirty dollars). It can be used to detect microwave leakage, but with considerable uncertainty as to the power density level of the leaks detected. A glowing tube indicates the presence of microwave power; however, a tube that does not glow is no indication that high levels are absent.

The following tabulation compares the characteristics of commercial devices incorporating thermocouple sensing elements, thermistors set in a bridge circuit, and a helix antenna with a diode detector circuit. Although these devices operate over different frequency ranges, they are all designed to include 2450 MHz; therefore, the devices will be compared at this frequency using a plane electromagnetic wave. This frequency was chosen since it is used for most microwave consumer products such as microwave ovens.

- (1) Sensitivity: Smallest readable indication
 - a. Thermocouple device: 0.01 mW/cm²
 - b. Thermistor device: 1 mW/cm²
 - c. Helix with diode detector: 0.5 mW/cm²

(2) Readable range

- a. Thermocouple device: 0.01 mW/cm^2 - 200 mW/cm^2
- b. Thermistor device: 1 mW/cm^2 - 500 mW/cm^2 with external attenuators
- c. Helix with diode detector: 0.5 mW/cm^2 - 10 mW/cm^2

(3) Ease of measurement

- a. Thermocouple device: This unit is completely portable. The three probes to be used with the meter are restricted to the three feet of cable attached to each probe. The sensing end of the probe is pointed toward the source of the radiation for optimum effect.
- b. Thermistor device: This unit is completely portable. The antenna can be fastened to the instrument body either directly or through a coaxial cable. However, the meter scale is small and difficult to interpret, and the antenna responds only to an electric field parallel to the wand or across the short dimension of the antenna horn depending on the model used.
- c. Helix with diode detector: The unit is completely portable and self-powered with the exception of mercury cells to operate a circuit to check meter operation. The antenna must be oriented toward the microwave source and has a beam width at half power response of about 55 degrees.

(4) Accuracy¹

- a. Thermocouple device: Approximately ± 25 percent at level of calibration of each probe
- b. Thermistor device: Approximately ± 25 percent at 10 mW/cm^2
- c. Helix with diode detector: -0 percent and + 59 percent. The inaccuracy approaches 59 percent at the higher end of the scale.

¹From manufacturers' specifications

(5) Reliability and repairability

- a. Thermocouple device: This instrument did not exhibit polarization sensitivity. However, it suffers probe failures at overloads of 50 percent above maximum range. Once a probe is burned out, the sensing device must be replaced and calibrated by a factory technician.
- b. Thermistor detector: This instrument is markedly affected by polarized microwave radiation. Either the probe must be held parallel to a linearly polarized electric field or else two readings 90 degrees apart must be taken to achieve accurate results. The instrument is not troubled by overloads with the exception of the attenuator mounted in series between the detector and the meter. However, the meter is troubled by zero drift.
- c. Helix with diode detector: This instrument will respond correctly to any direction of plane polarization, but will not respond correctly to elliptically polarized waves. No experience has been encountered with repairability of the instrument.

(6) Cost

- a. Thermocouple device: \$885.00
- b. Thermistor device: \$605.00
- c. Helix with diode detector: \$450.00

(7) Stability

- a. Thermocouple device: The thermocouple instrument is quite stable and its accuracy has little temperature dependence (8 percent change from initial value when brought from 5°C to 22°C).
- b. Thermistor device: The thermistor device has a rather unstable zero adjustment and its accuracy specifications are exceeded at extremes of temperature (30 percent change from initial value when brought from 5°C to 22°C).
- c. Helix with diode detector: No information about the stability or the temperature dependence of measurement accuracy of the instrument using the helix with the diode detector is presently available.

CONCLUSIONS

There are advantages and limitations for all the various instruments described in this report. Almost all of the instruments will serve some useful purpose within their limitations, while the particular frequency and test conditions may favor the selection of one device over another. As a result of the tests outlined in this report, it was found that the thermocouple device is best suited to measure leakage close to a slot source such as a microwave oven at the frequency of 2450 MHz.

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KEY WORDS: Microwave, Microwave Oven, Power Density, Survey Instrument, Leakage, Bolometer, Thermistor, Neon Tube, Antenna

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